UTILITY ADVANCED TURBINE SYSTEMS PROGRAM (ATS)

TECHNICAL READINESS TESTING AND

PRE-COMMERCIAL DEMONSTRATION

CONTRACT NO. DE-FC21-95MC32267

FINAL

QUARTERLY TECHNICAL PROGRESS REPORT TPR-19
For the Period October 1, 2000 to December 31, 2000

to the

U.S. DEPARTMENT OF ENERGY

Office of Fossil Energy

National Energy Technology Laboratory

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Submitted by

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ABSTRACT

The objective of the ATS program is to develop ultra-high efficiency, environmentally superior and cost competitive gas turbine systems for base load application in utility, independent power producer and industrial markets. Specific performance targets have been set using natural gas as the primary fuel:

- System efficiency that will exceed 60%(lower heating value basis) on natural gas for large scale utility turbine systems; for industrial applications, systems that will result in a 15% improvement in heat rate compared to currently available gas turbine systems.
- An environmentally superior system that will not require the use of post combustion emissions controls under full load operating conditions.
- Busbar energy costs that are 10% less than current state-of-the-art turbine systems, while meeting the same environmental requirements.
- Fuel-flexible designs that will operate on natural gas but are capable of being adapted to operate on coal-derived or biomass fuels.
- Reliability-Availability-Maintainability (RAM) that is equivalent to the current turbine systems.
- Water consumption minimized to levels consistent with cost and efficiency goals.
- Commercial systems that will enter the market in the year 2000.

In Phase I of the ATS program, Siemens Westinghouse found that efficiency significantly increases when the traditional combined-cycle power plant is reconfigured with closed-loop steam cooling of the hot gas path. Phase II activities involved the development of a 318MW natural gas fired turbine conceptual design with the flexibility to burn coal-derived and biomass fuels. Phases I and II of the ATS program have been completed. Phase III, the current phase, completes the research and development activities and develops hardware specifications from the Phase II conceptual design.

This report summarizes Phase III extension activities for a three month period. Additional details may be found in monthly technical progress reports covering the period stated on the cover of this report. Background information regarding the work to be completed in Phase III may be found in the revised proposal submitted in response to A Request for Extension of DE-FC21-95MC32267, dated May 29, 1998 and the Continuing Applications of DE-FC21-95MC32267, dated March 31, 1999 and November 19, 1999.

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EXECUTIVE SUMMARY

The objective of the ATS program is to develop ultra-high efficiency, environmentally superior and cost competitive gas turbine systems for base load application in utility, independent power producer and industrial markets. In Phase I of the ATS program, Siemens Westinghouse found that efficiency significantly increases when the traditional combined-cycle power plants is reconfigured with closed-loop steam cooling of the hot gas path. Phase II activities involved the development of a 318MW natural gas fired turbine conceptual design with the flexibility to burn coal-derived and biomass fuels. Phases I and II of the ATS program have been completed. Phase III, the current phase, completes the research and development activities and develops hardware specifications from the Phase II conceptual design. This report summarizes Phase III activities for the three month period October 1, 2000 to December 31, 2000.

Phase 3 extension originally involved no load testing of the ATS turbine generator. A redefinition of Phase 3 extension tasks was submitted as a continuing application to the Department of Energy on March 31, 1999. The continuing application continues to focus on critical engineering, manufacturing, development and testing to verify the readiness of ATS technology for commercial application. Approval of the continuing application was received in June 1999. A second continuation application was submitted in November 1999.

Final piping and wiring connections are complete for the new combustion rig. The rig was successfully commissioned on 12/15/00. The fuel heaters were damaged during the 2nd test run and are in the process of being replaced with completion expected in February. Agilis has been issued a PO to design and fabricate the hot cascade vane pack.

The turbine blade root verification testing is waiting for Hamilton to complete the broach machining of the test disc. The dummy blades have been cast and are ready except for minor rework being required on two.

STC is analyzing the catalyst from the 500-hour durability testing. SWPC was awarded a NIST contract on catalytic combustion development and based on this the agreement with PCI is in process of being re-negotiated.

Perkin Elmer has completed all rim brush seal testing. They delivered the final brush seal report to SWPC Orlando. The results have been reviewed and are satisfactory.

The internal aluminide qualification requirements issued as 22T3872, the final draft of the PD-Spec, has been sent to standards to start the signature process. A second, successful, processing trial was conducted on coating the ATS transition internal channels.

ORNL's analysis for the weld microstructures of the modified IN-939 alloys is complete. An additional alloy from the previous series of experiments will be tested at Cincinnati Test Labs for mechanical properties.

APS coated specimens coated specimens were cycled at Waltz Mill high-heat flux test facilities

under service relevant temperature conditions to determine a cyclic failure mechanism. The test showed no cyclic dependencies except when hold times are very short.

John Hopkins University (JHU) is currently developing x-ray diffraction transmission Laue imaging technique for characterizing single crystal (SX) components. JHU is modified the specimen manipulating test bed to further accommodate this testing.

Testing to assess the effect of strain ratio and coating on the low cycle fatigue properties of IN939 at temperatures of 800 and 900°C with a strain range of 0.5% and hold times of up to 300 seconds is almost complete.

The Space Act Agreement from NASA for the proposed rig testing of BFH in NASA's high-pressure burner rig is currently under review at SWPC. The testing is expected to start by the end of January. Stress rupture testing of BFH coated Hastelloy X substrates reveal that the coated substrates meet or exceed the requirements for Hastelloy X at 15 ksi and 1500°F.

The Hot Cascade casting effort is now complete. The cast vanes have been shipped to STC for temporary storage. Two scrap vanes have been shipped to TurnTech and one to Metem for conventional and non-conventional machining operations. PCC has completed the first casting trial for the TLP bonded vane. The preliminary results indicate that the mold strength is inadequate.

Preliminary performance data have been estimated for IGCC and PFBC plants using ATS turbines. This data is being reviewed prior to more detailed work on the combustor conceptual designs.

SWPC management, who feels we need a full agreement in place quickly, rejected the letter of agreement signed by PCI. Negotiations with PCI are continuing toward that end, and a target date for the full agreement has been set at Feb. 15th 2001.

INTRODUCTION

BACKGROUND

The National Energy Strategy (NES) calls for a balanced program of greater energy efficiency, use of alternative fuels, and the environmentally responsible development of all U.S. energy resources. Consistent with the NES, an U.S. Department of Energy (DOE) program has been created to develop Advanced Turbine Systems (ATS). The Siemens Westinghouse ATS Program is funded and directed by DOE's National Energy Technology Laboratory (NETL). The technical ATS requirements are based upon two workshops held in Greenville, SC that were sponsored by DOE and hosted by Clemson University. The objective of this 8-year program, managed jointly by DOE's Office of Fossil Energy, and, Office of Conservation and Renewable Energy, is to develop natural-gas-fired base load power plants that will have cycle efficiencies greater than 60%, lower heating value (LHV), be environmentally superior to current technology, and also be cost competitive. The program will include work to transfer advanced technology to the coal- and biomass-fueled systems being developed in other DOE programs.

METHODOLOGY

The Advanced Turbine Systems program is structured into four elements:

- Innovative Cycle Studies
- Utility Advanced Turbine Systems
- Industrial Advanced Turbine Systems
- Technology Base

Within each program element there are several planned phases. For example, the Innovative Cycle Studies element includes two phases.

- Program Definition/Planning Studies
- Concept Development

The objective of the ATS Program is to develop ultra-high efficiency, environmentally superior, and cost-competitive gas turbine systems for base-load application in utility, independent power producer, and industrial markets. Specific performance targets have been set using natural gas as the primary fuel:

- System efficiency that will exceed 60% [lower heating value basis (LHV)] on natural gas for large-scale utility turbine systems; for industrial applications, systems that will result in a 15% improvement in heat rate compared to currently available gas turbine systems.
- An environmentally superior system that will not require use of post-combustion emissions controls under full-load operating conditions.
- Busbar energy costs that are 10% less than current state-of-the-art turbine systems, while meeting the same environmental requirements.
- Fuel-flexible designs that will operate on natural gas but are also capable of being adapted to operate on coal-derived or biomass fuels.
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In Phase I of the ATS program, Siemens Westinghouse found that efficiency significantly increases when the traditional combined-cycle power plants is reconfigured with closed-loop steam cooling of the hot gas path. Phase II activities involved the development of a 318MW natural gas fired turbine conceptual design with the flexibility to burn coal-derived and biomass fuels. Phases I and II of the ATS program have been completed. Phase III, the current phase, completes the research and development activities and develops hardware specifications from the Phase II conceptual design. Phase 3 extension activities focus on critical engineering, manufacturing development, and testing to verify the readiness of ATS technology for commercial applications.

This report summarizes Phase III extension activities for a three month period. Additional details may be found in monthly technical progress reports covering the period stated on the cover of this report. Background information regarding the work to be completed in Phase III may be found in the revised proposal submitted in response to A Request for Extension of DE-FC21-95MC32267, dated May 29, 1998 and the Continuing Applications of DE-FC21-95MC32267, dated March 31, 1999 and November 19, 1999.

RESULTS AND DISCUSSION

11.0 PROGRAM MANAGEMENT

There were no scheduled activities for this quarter.

12.0 DEVELOPMENT ENGINEERING

12.1 VERIFICATION TESTS

Vane Cascade Final piping and wiring connections were completed for the new combustion rig. System checkouts are complete. The new combustion test rig was commissioned successfully on 12/15/00. Two tests were carried out. The second test was terminated prematurely due to variations in the combustor inlet flow. The fuel heaters were subsequently damaged due to the fuel flow not being shutdown. Testing will resume after heater repair is completed and is expected in early February. A purchase order was issued to Agilis for design and fabrication of the hot cascade vane pack. The contract has been signed and work has been initiated.

Turbine Root Blade Verification A quote was received and approved for Hamilton to provide the test disc and machining work necessary to complete this test. Dummy blades have been casts with two requiring minor rework. Hamilton will provide a schedule for the machining work and testing.

Turbulator Model Tests No scheduled progress to report.

12.2 C. T. ENGINE DEVELOPMENT ENGINEERING

Combustion System Development STC is analyzing the catalyst from the 500-hour durability testing. SWPC was awarded a NIST contract on catalytic combustion development and based on this the agreement with PCI is in process of being re-negotiated. The progress of this is slow and an extension on the NIST contract start date until December 1st has been requested. The design work is continuing at STC with the testing to begin in the STC rig after the agreement with PCI has been signed.

Advanced Seal Development Perkin Elmer has completed all rim brush seal testing. Test results show that the Haynes 214 bristles are good up to 1600° F. but not at higher temperatures, which are required. The bristles exhibit high wear and induce excessive wear on the CM247 material, which the bristles run on. Perkin

Elmer delivered the final brush seal report to SWPC Orlando. All results have been reviewed and are satisfactory. This will conclude this program.

Thin Wall Casting Development This program has been combined with the Row 1 Vane Alternative Design program.

12.3 MATERIALS DEVELOPMENTAL ENGINEERING

Steam Effects on Materials The internal aluminide qualification requirements issued as 22T3872, the final draft of the PD-Spec, has been sent to standards to start the signature process. The report on the initial steam corrosion test is in process. A second processing trial was conducted on coating the ATS transition internal cooling channels. The preliminary indication taken from witness coupons is that the modifications were successful in increasing the coating thickness to meet the specification.

Advanced Vane Alloy ORNL's analysis for the weld microstructures of the modified IN-939 alloys is complete. Two of the alloys have been heat-treated using the 4-step production heat treat process and will be weld tested to determine any change in weldability. An additional alloy from the previous series of experiments will be tested at Cincinnati Test Labs for mechanical properties. The findings of the research at ORNL indicate an enhanced weldability of this alloy.

TBC Life Prediction APS coated specimens were cycled at Waltz Mill high heat flux test facilities under service relevant temperature conditions to determine a cyclic failure mechanism. Both TGO thickness and hold time at high temperature were varied. The experiments showed no cyclic dependency on failure time for hold times, typical for industrial gas turbines. A cyclic dependency of failure time was only observed when the hold times were very short. Then, the total hot time to failure decreases rapidly with decreasing hold time per cycle. The experimental results demonstrated also very clearly that specimens with less TGO exceed the failure times and failure cycles of heavier oxidized specimens.

ATS NDE X-ray diffraction transmission Laue imaging technique is currently being developed by John Hopkins University (JHU) for characterizing SX components (single crystal orientation, imperfections, and secondary crystal detection). JHU has recently modified the specimen manipulating test-bed that can rotate and translate the specimen while producing x-ray diffraction Laue images. This test-bed will be used for both earlier developed asymmetric crystal topography (ACT surface examination) and through-transmission Laue imaging (volumetric examination).

TMF testing row 1 blade alloy Testing to assess the effect of strain ratio and coating on the low cycle fatigue properties of IN939 at temperatures of 800 and 900°C with a strain range of 0.5% and hold times of up to 300 seconds is almost complete. TMF testing of IN939 has started and progressing to plan. Testing will continue throughout the first quarter of 2001.

Ring Segment Abradable Coating Development The Space Act Agreement from NASA for the proposed rig testing of BFH in NASA's high pressure burner rig is currently under review at SWPC. The testing is expected to start by the end of January. Stress rupture testing of BFH coated Hastelloy X substrates reveal that the coated substrates meet or exceed the requirements for Hastelloy X at 15 ksi and 1500°F. An inspection plan to inspect the BFH ring segments installed in a 501D5 engine at Dow Chemical on February 8th is in place. The ring segments will have been in operation for 22,000 hrs at base load by this date.

Alternate Alloy Development No scheduled activity this quarter.

Liquid Metal Cooling Casting No scheduled activity this quarter.

12.4 C. T. MANUFACTURING ENGINEERING

Row 1 Blade and Vane Alternative Design The Hot Cascade casting effort is now complete. The cast vanes have been shipped to STC for temporary storage. Two scrap vanes have been shipped to TurnTech and one to Metem for conventional and non-conventional machining operations. PCC has completed the first casting trial for the TLP bonded vane. The preliminary results indicate that the mold strength is inadequate. PCC has suggested several solutions to this problem and will implement them for the 2nd casting trial, which should complete by the end of January. A purchase order for the bonding tools was issued to JA Design and the initial engineering work has been started.

12.5 GENERATOR DEVELOPMENTAL ENGINEERING

ATS Class G Stator Development. No scheduled activity.

12.6 ADAPTATION TO COAL AND BIOMASS FUELS

Preliminary performance data have been estimated for IGCC and PFBC plants using ATS turbines. This data is being reviewed prior to more detailed work on the combustor conceptual designs. For the PFBC application, high-temperature toroidal manifolds have been configured. These manifolds deliver 1600°F syngas and vitiated air to the syngas combustors, and extract compressed air from the turbine for the carbonizer and PFBC. A review of the preliminary performance

data for IGCC and APFBC plants with ATS turbines resulted in minor adjustments to the IGCC performance. The topical report for this task is in process.

13.0 C. T. MANUFACTURING DEVELOPMENT AND TOOLING

13.1 DELETED

13.2 MANUFACTURING & TOOLING DEVELOPMENT ENGINEERING

No scheduled activity.

13.3 DELETED

13.4 MANUFACTURING VERIFICATION TESTS

No scheduled activity.

14.0 ATS TECHNOLOGY VERIFICATION PROGRAM

14.1 STEAM COOLED COMPONENT & AERO-THERMAL DESIGN VALIDATION TEST

Task is complete.

14.2 ADVANCED VISCOUS COMPRESSOR TEST

Task is complete.

14.3 CATALYTIC COMBUSTOR TEST

SWPC management, who feels we need a full agreement in place quickly, rejected the letter of agreement signed by PCI. Negotiations with PCI are continuing toward that end, and a target date for the full agreement has been set at Feb. 15th 2001. ATCC3 module #3 is being fabricated, but currently does not have the catalytically coated parts to finish it and resume testing. A vibration test has been set up using module #1 to determine the natural frequencies and damping characteristics of the design.

14.4 STEAM COOLED VANE TEST

No scheduled activity.